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THE TEACHING OF AIRCRAFT DESIGN

by

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SUMMARY

Aircraft Design has been taught at the College of Aeronautics since 1946. The course is at postgraduate level and is of two years duration. In the first year the students are given three exercises in component design which aim to teach a logical approach and the fundamentals of the subject. During the second year each student works as a member of a team engaged in the design of a complete aircraft, which is chosen to be of a type currently being investigated by industry. The project aircraft invariably incorporates experimental features and the design work is therefore of the nature of research.

* The paper is based upon papers presented by the authors to the Session on 'The Education and Training of Technological Designers' at the Further Education Staff College, Blagdon, on January 20th 1964.

Contents

1. Introduction

Aircraft Design has been taught at the College of Aeronautics since its inception in 1946. The teaching policy adopted at that time has changed little in principle and subsequent experience has shown it to be correct. The techniques employed to implement the basic policy have been improved considerably with the passage of time. Although this basic policy and the techniques apply specifically to the teaching of aircraft design, there is no reason why they should not be applied in any field where it is essential to combine a background of theoretical knowledge with the art of the subject. Frequently so called design teaching consists either of a presentation of theoretical methods of analysis or a discussion of artistic synthesis, but both aspects are essential in a properly organised and well balanced course. A good designer must be able to correctly emphasise both synthesis and analysis so that an optimum result is achieved, and this need for a balanced outlook and 'feel' for the problem has often given rise to the assertion that good designers are born and not made. There may be some truth in this but modern technology is so complex that born designers need extensive training, and experience has shown that correct teaching can exploit the latent potential of many who are not so gifted.

2. Basic policy

Aircraft Design is an extremely fluid subject and has advanced at an increasing rate in recent years. The frontiers of knowledge are being continuously extended and there can be no classical text books. The teaching staff must keep up to date but at the same time must not lose sight of fundamentals or real practice. The student must have a broad and deep background of both experience and theory before he is capable of tackling design work, or for that matter is ready to receive instruction in the subject.

It is considered that design teaching of the standard required can only be carried out at post graduate level. The course in aircraft design is of two years duration and although the second year differs in some respect from the first, it is arranged to follow on logically from it so that together the two years form an integrated whole. Occasionally certain specially qualified and selected students are admitted directly into the second year, but without exception they have found themselves at a considerable disadvantage as a result of their lack of first year background. In fact the first year of the course is essential to bring all the students to a common level. Those whose theoretical training is adequate need to be given a practical background, whilst those who have had engineering training require to rationalise their ideas and consolidate their theoretical knowledge.

The design exercises and studies used for both years of the course are never repeated. The necessary preparation puts a big strain on the teaching staff but this system has the desirable result of keeping the staff up to date and research work often results from the second year studies. Although the course work is not normally security classified, the staff do have clearance which enables them to visit industrial organisations engaged on military work, and sit on government committees. Frequent visits to actual design and manufacturing establishments are essential for the staff. In addition, the staff of the department of Aircraft Design constitute a Design Organisation, approved by the Air Registration Board, which is responsible for the airworthiness of all College aircraft. A small professional drawing office staff is engaged in this and associated contract work and is controlled by the teaching staff.

In the aircraft industry all drawing offices have large drawing stores which are in constant use during the design of a new aircraft. Approximately 10,000 drawings are necessary for the production of a single medium sized modern aircraft and only a discerning and experienced designer can make full use of them. However, it is essential for the students to learn from past experience, whether the examples be good or bad, and a demonstration laboratory has been established so that they can see and handle things as they are. Figures 1 and 2 are photographs of parts of this laboratory and give some indication of the scope of the exhibits which range from small parts and manufacturing techniques to complete aircraft and missiles. Although the aircraft are not kept in flying condition many of them are used in structural and dynamic tests.

Two drawing offices are provided for use by the students, one of which is illustrated in Figure 3. The exhibits in the demonstration laboratory are supplemented by perspective drawings of aircraft which show details of their layout, construction and systems. In addition, the professional drawing office, which is in the same building, has a reference library which consists of the catalogues and publications essential in an approved organisation, and these are available for use by the students. All students are given copies of specially prepared volumes of design and stressing data sheets.

3. The first year design work - teaching techniques

A complete aeroplane requires a tremendous design effort and one of the major teaching problems is the compression of the essential knowledge into a course of limited length. At postgraduate level the students have different backgrounds and abilities and must be taught individually, so that time is the constant enemy of both student and staff. During the first year the students are given an example in each of the three terms. The total formal teaching time is about 48 hours in the drawing office, but as a student spends about twice this time in addition on his set work the total design time amounts to about 150 hours. This is divided about equally between design and drawing on the one hand and stressing and calculations on the other. The formal drawing office time is supplemented by lectures of which some four per week, or 120 hours per year, are directly relevant to the design work. A previous knowledge of engineering drawing is assumed.

Each design example is a component of an aircraft and is chosen to illustrate both fundamental concepts and detail design. The student prepares one or two drawings which give the principal dimensions and essential details, a complete stressing report and a weight estimate. Emphasis is placed on the need for reliability, ease of manufacture and cheapness in addition to meeting the prescribed loading conditions.

Consideration of a first term example suffices to show how the basic design logic is evolved. Figure 4 is a simplified diagram of a hydraulically operated air brake. The student is required to design the supporting beam and jack attachment. Although this is a simple exercise it does introduce a variety of problems, these being illustrated in Figure 5. Initially the student is encouraged to make the simplest possible calculations and is guided in making the appropriate assumptions. He then refines his design by an iterative process until an optimum is achieved. The diagram indicates the sequence of the synthesis and analysis.

1. The depth of the supporting beam at the jack attachment point must be estimated so that there is an adequate second moment of area. The horizontal component of the jack load is assumed to be taken in shear along the air brake housing wall.

2. The depth of the beam at its ends is determined by the number and size of the shear connections.

3. The shear, bending and bearing loads enable the size of the jack attachment to be evaluated.

4. The rivet group with its offset bending moment is analysed.

5. The lateral dimensions of the beam are considered and the torsional stiffness is checked.

6. At this stage it is possible to complete the jack attachment bracket design.

7. The beam webs can be checked in shear.

8. Local instability of the beam compression flange must be checked.

9. The jack fitting attachment to the flanges is designed.

10. The shear flow in the beam flanges is used to design the top plate and housing wall attachments.

11. The thickness of the beam end shear cleat is checked to ensure adequate bearing strength.

12. Finally manufacturing details, such as bend radii, and refinements are added in accordance with the design data sheets.

The student spends a total of 25 to 30 hours on this example and Figure 6 shows a completed design. The main lesson that the student learns from this type of exercise is that in aircraft design every detail, however small, whose failure endangers the safety of the aircraft must be checked for strength and stiffness. All reserve factors must be quoted for future reference.

The second term example is more complex and frequently involves the design of a fuselage frame with a concentrated applied load, such as at a fin spar or undercarriage leg. Both the attachment fitting and main structural member are designed in detail, and the problem is arranged so that the students apply the theoretical structures course work. The opportunity is taken to introduce a fatigue requirement and the concepts of a 'faile safe', or a 'safe life' design must be considered.

In the third term the example is usually an aircraft control surface. Many mechanical and structural design problems can be embodied at this stage and the exercise serves to lead in to the second year work. Consideration has to be given to the hinges and hinge brackets, shrouds, balance, and seals as well as to the basic structure which is inevitably designed as much by stiffness and local deflections as by strength. Figures 7 and 8 are reproductions of the drawings which result from such an exercise.

4. The second year design work

4.1 The aim of the course

The aim of the second year work is to produce a man who has not only had realistic practical design experience in the field in which he will subsequently work, but also whose outlook is such that he will gain in design stature as his experience widens. Except in rare cases the student does not design a complete aircraft but proceeds from the first year examples to a major aircraft component. The overall aspect is covered by lecture courses, especially those concerned with aircraft and project design. These give the student the necessary background to call upon when his subsequent experience in industry is sufficient to enable him to tackle the task of a complete aircraft design.

In an attempt to produce designers of the required calibre the second year is arranged with certain basic concepts in mind.

a) It is essential that the student has practical design experience of a problem which is representative of the type which he will subsequently face in industry. The form and magnitude of this problem must be chosen so that it covers a comprehensive set of requirements and yet at the same time enables the student to get down to the design of details.

b) Each student must be given an individual and unique task so that he is forced to think for himself and stand by his own decisions. In no circumstances must it be possible for him to be carried along with the rest of the class.

c) The experience must be on as broad a base as is feasible and the student must be aware of requirements which conflict with his own. Since most industrial design is the result of teamwork he must not be allowed to work in isolation. Therefore each student's component must be part of a complete study, and he himself a member of the team working on it.

d) Although the task chosen must be different from anything previously studied it must not be so different as to render it virtually insoluble in the time available. This frequently implies an association of the component with a research investigation which may or may not be undertaken by the student himself.

e) The basic design chosen for the team should in itself be a research investigation. For example it might introduce novel engineering ideas thought to be worthy of study, or it could be conceived to enable a direct comparison with another design to be made. The study indicates areas where research is necessary.

It is immediately obvious that these exacting requirements are not easily met. The teaching staff must be prepared to spend a considerable time in the preparation and supervision of the student's work and must naturally have had extensive experience themselves. Even with the first year work behind him the student needs careful guidance, especially in the early stages of his work. This is inevitable as the limited time available means that initial decisions must be taken quickly.

4.2 The design project

In each academic year the team of students work on a project aircraft and are individually responsible for a substantial part of the airframe, a system, or a mechanical component. The aircraft is chosen to be representative of a type which is of current interest to industry and it invariably incorporates some feature which extends the bounds of existing knowledge. This feature helps to fulfil the requirement that the work should be a research investigation in its own right, it assists in the introduction of originality in the work of the individual students and has the effect of exciting their interest, enthusiasm and imagination. Every possible effort is made to make the project realistic. This is no easy task when the design is of advanced concept and it is achieved partly by consultation with experts, including design teams, and partly by the extensive initial work on the part of the staff.

The size of the aircraft is dictated to some extent by the number of students involved. This is inevitable as each individual task must be of sufficient magnitude to stretch the student, but not so large as would prevent detail design work from being undertaken. Maximum use must be made of the time available and no design can be considered as being acceptable until the details have been worked out. Some eighteen to twenty students can cover a large aircraft adequately whilst a minimum of ten are required to achieve a satisfactory result on a small aircraft. During the past few years a pattern has emerged in the choice of aircraft types for the project studies. The designs fall into two broad categories, being either of advanced and novel concept or relatively conventional but incorporating an unusual feature or requirement. An aircraft from each of these categories is chosen in alternate years, thus design studies of two supersonic airliners were separated by an investigation of a subsonic freighter capable of vertical take off and landing. This procedure has been found to be necessary as at least two years are required to complete the necessary preparations for an advanced design. Guided missile projects have occasionally been used in addition to aircraft, and space craft are being considered for the future.

The preparatory work for one of the advanced projects follows an established routine. At least two years before the design is to be ready for the students a general requirement is formulated for a particular type of vehicle. This may arise as the result of research being undertaken either within the College or outside. A preliminary study indicates the major problem areas and these become topics for detailed investigation by both staff and students. Without these investigations there is insufficient background knowledge to enable the design to be studied to completion. Some six months before the beginning of the academic year a detailed requirement is established. The external form of the aircraft is determined, analysed aerodynamically and refined until optimum performance is achieved. A layout of internal components is prepared, the weight and inertia loadings evaluated, and the structure analysed briefly in regions where problems seem likely to occur. Additional calculations are made where it is thought to be desirable to check such items as systems, aero-elasticity and controls. The feasibility of the design is established and the staff are able to anticipate the problems likely to be encountered by the students. This process of initial project design culminates in the production of a brochure which provides the students with all the information they require to start their work. The brochure contains data of two types. In addition to an outline of the background, requirements and performance of the aircraft, there are tables and diagrams which give the essential load distributions and aerodynamic derivatives.

The preparation for a conventional design closely follows the last part of the procedure used for advanced designs, and it has been found that all the necessary work can be completed by two members of staff in about three months.

4.3 The method of teaching

The salient features of the forthcoming project are outlined to the students towards the end of the first year of their course. They are given the opportunity of choosing the component which they would like to design, and although it is rarely possible to satisfy everyone it is usually possible to ensure that each student is allocated a component of the right type. It is possible to select potential leaders on the basis of the first year design work, and the component allocation is arranged so that these have the responsibility for parts which are likely to exert the maximum overall influence. Figure 9 shows a typical allocation of components. In addition each student is given a subsidiary research task which frequently involves him in the design of test equipment. No specific work is set for the summer vacation but the students are given suggestions for suitable reading to meet their individual requirements.

Before any student can examine his own component in detail it is necessary to analyse the loading on the whole aircraft so that overall shear force, bending moment and torque diagrams can be drawn. This is a major task due to the wide variety of operating conditions and requirements, and the need for a high order of accuracy. The students are divided into groups for the purpose of load analysis. Each group has responsibility for specified loading cases and produces results which are required both by the members of the group and by the rest of the team. A team spirit is built up from the outset and the students are forced to realise their interdependence upon one another. As soon as the load analysis is complete the students are able to concentrate upon their individual tasks, but naturally have to consult one another frequently when components are adjacent or interact.

One of the important means of supervision is the project meeting. This is held regularly, normally on a weekly basis but more frequently when this becomes necessary. Every student is expected to report his progress at each of these meetings. He must present any results he has obtained and is encouraged to produce scheme drawings at an early stage. The work is discussed and constructively criticised by both the staff and other students, and thus each student benefits from the experience of the staff and the work of the rest of the team. The project meetings are backed up by supervision on an individual basis. This is given either when a student has a specialised problem or in the form of guidance with detail design on the drawing board. It has been found that many of the students' design problems stem from an inability to visualise or express them on paper. In these cases the student is encouraged to make a simple space model. When the problem is more of a detail type it is usual to make suggestions in the form of sketches but leave the student to translate the ideas into a working proposition. Frequently there are two or more ways of tackling a problem, and ideally the student should investigate all the possibilities. However, in the restricted time which is available it is usually necessary to assist him in coming to a decision based largely on qualitative evidence. When conflicting interests arise a member of staff assumes the role of chief designer and as a basis for arbitration requires that the best overall aircraft design should be achieved. The importance of a high standard of detail design is frequently emphasised.

Many of the design problems encountered on aircraft are numerically complex and considerable use is made of the College's 'Pegasus' computer in an endeavour to alleviate this difficulty. Standard programmes have been developed for some of the more complex, but nevertheless common, structural problems, such as frame analysis.

The design work is the students major task during a period of two terms which is equivalent to about six months work allowing for the intervening vacation. The total time devoted to the design varies between 600 and 800 hours. At the end of the period the student is required to submit the results of his investigation for assessment. In addition to his contribution to the load analysis each student hands in a set of drawings and calculations and a report which discusses and explains the work. There are usually seven to ten drawings and they contain sufficient detail to show that all the main problems have been analysed in detail. The calculations are as extensive as is necessary to substantiate the drawings, and the report is expected to draw conclusions as to the success of the work including a comparison between the estimated weight and the initial predicted value.

In the case of the vertical take off freighter(1) previously mentioned, the team produced a total of 130 drawings which covered all the essential aspects of the design. The total staff and student time on this 'conventional' design amounted to about 10,000 hours.

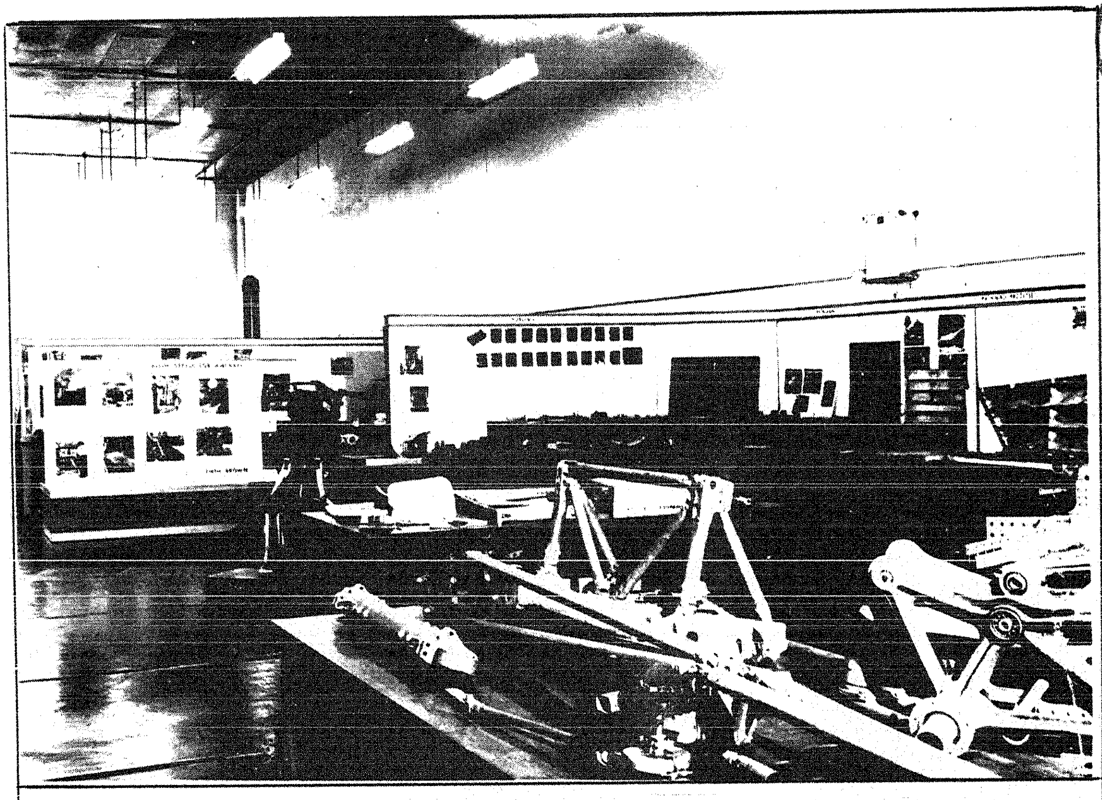
5. Conclusions

The method of design teaching which has been described has been developed over a period of some sixteen years. Although it requires a considerable effort on the part of both the staff and the students it is believed that this is essential if the subject is to be taught satisfactorily. Only when the student has reached post graduate level has he acquired the necessary background knowledge to benefit fully from a course in design. The course itself must be arranged to enable the student to obtain individual experience in the detail design of a complex component, but an element of teamwork is desirable. It is essential for the teaching staff to keep up to date, preferably by associating the design work with research.

Some of the students who have participated in the course have left the aircraft industry and are engaged in design work in other fields, where they have found their training to be of great value.

References

1. Howe, D. — Aircraft Design Studies - Conventional and Vertical Take Off Freighters. College of Aeronautics Report No. Aero 171 December, 1963.



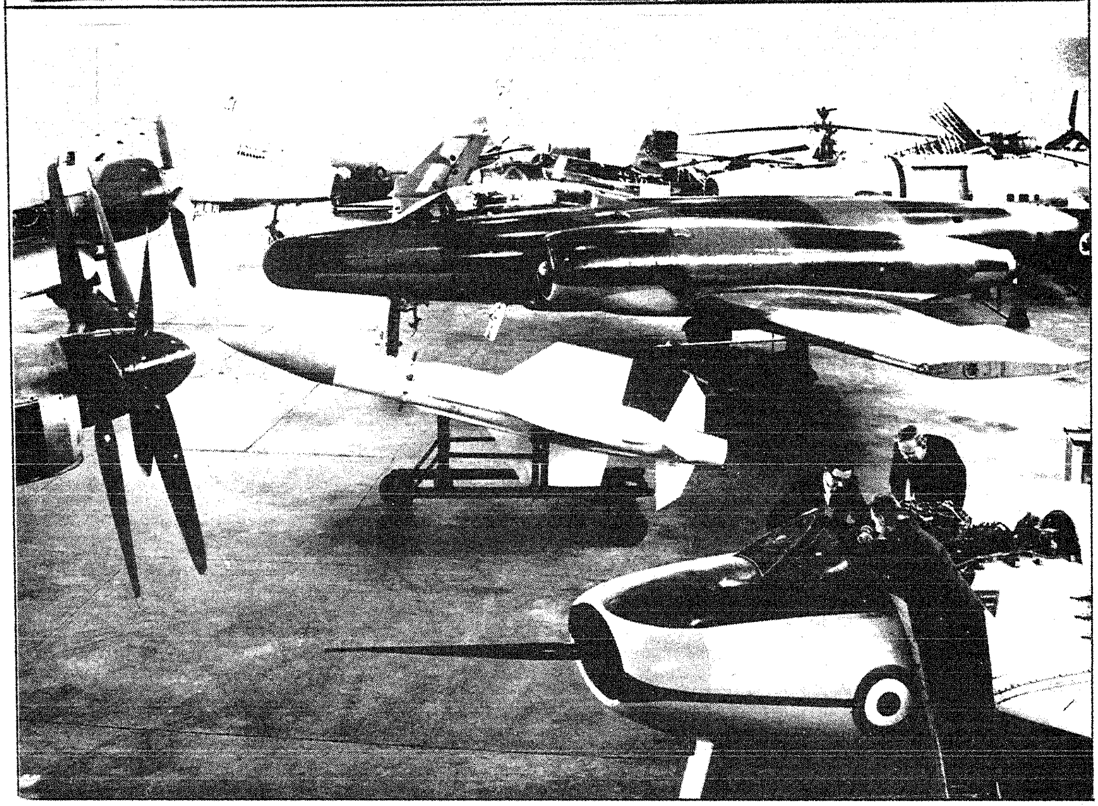


FIG. 1. DEMONSTRATION LABORATORY - COMPONENT DISPLAY

FIG. 2. DEMONSTRATION LABORATORY - AIRCRAFT DISPLAY

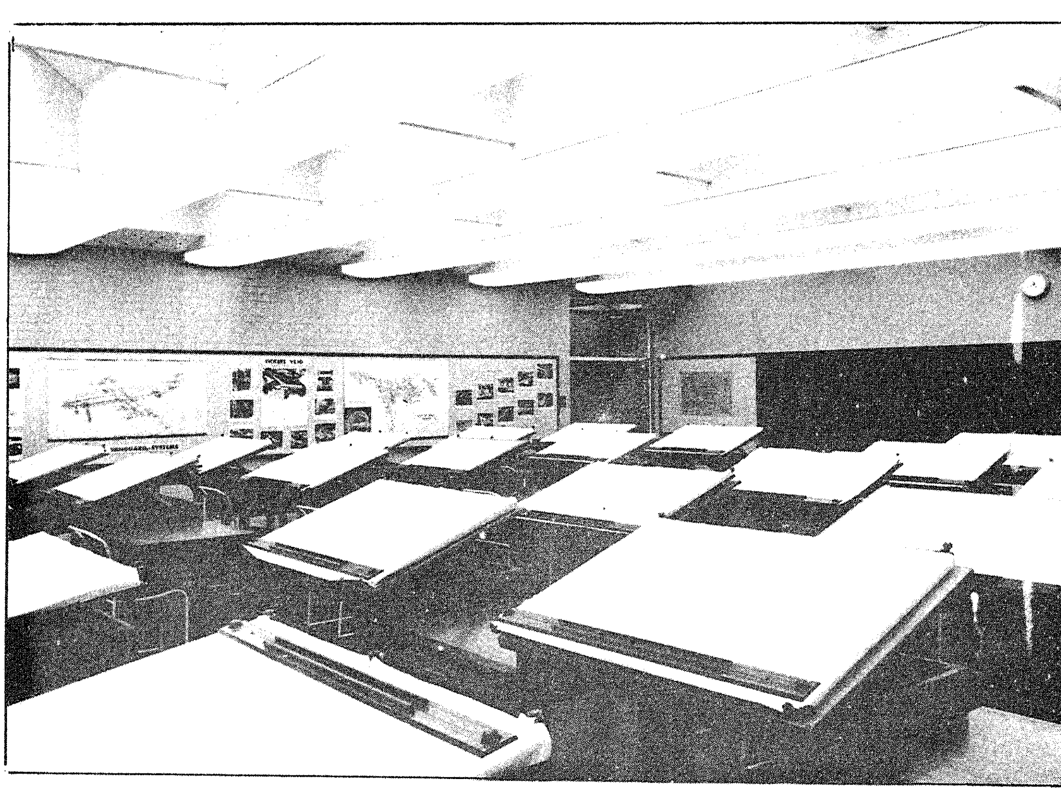


FIG. 3. FIRST YEAR DRAWING OFFICE

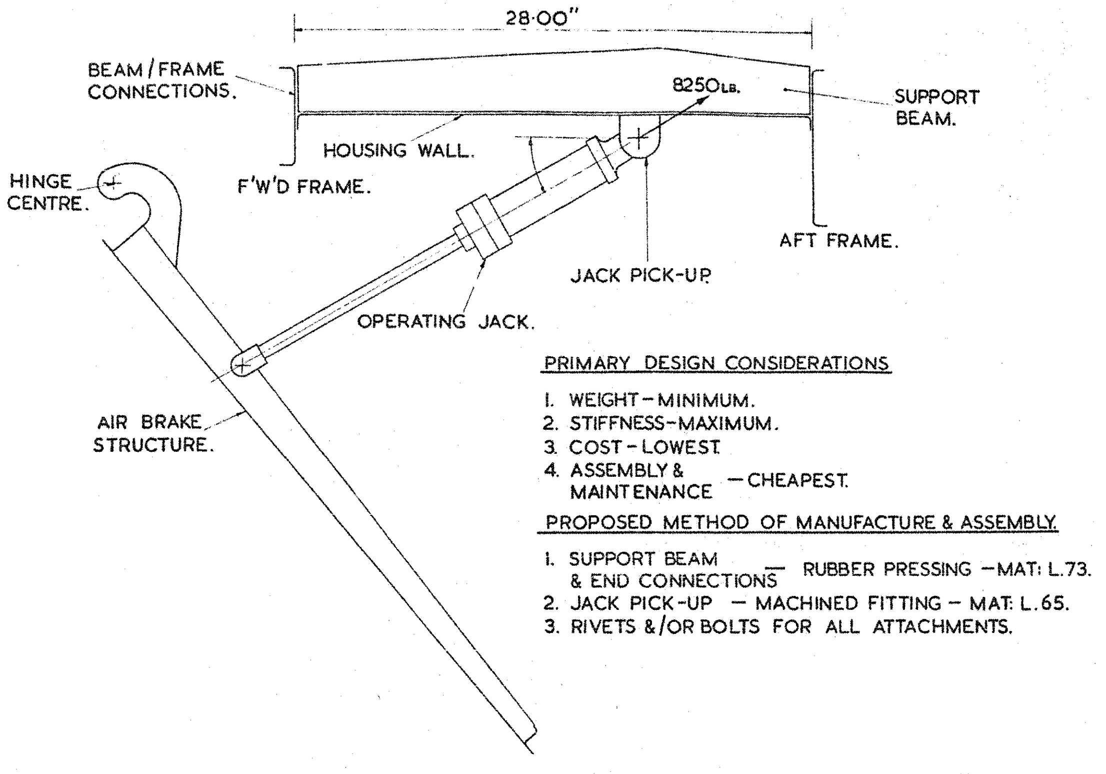


FIG. 4. SIMPLIFIED DRAWING OF 1st TERM EXAMPLE

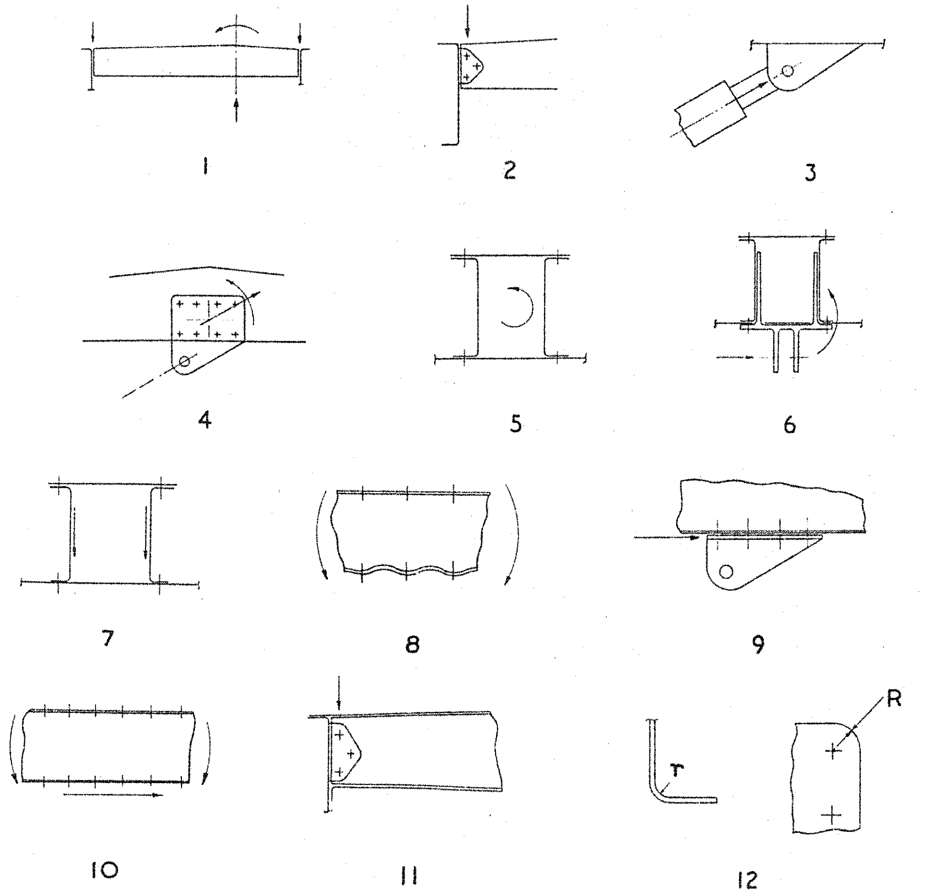


FIG. 5. DESIGN PROCEDURE OF 1st TERM

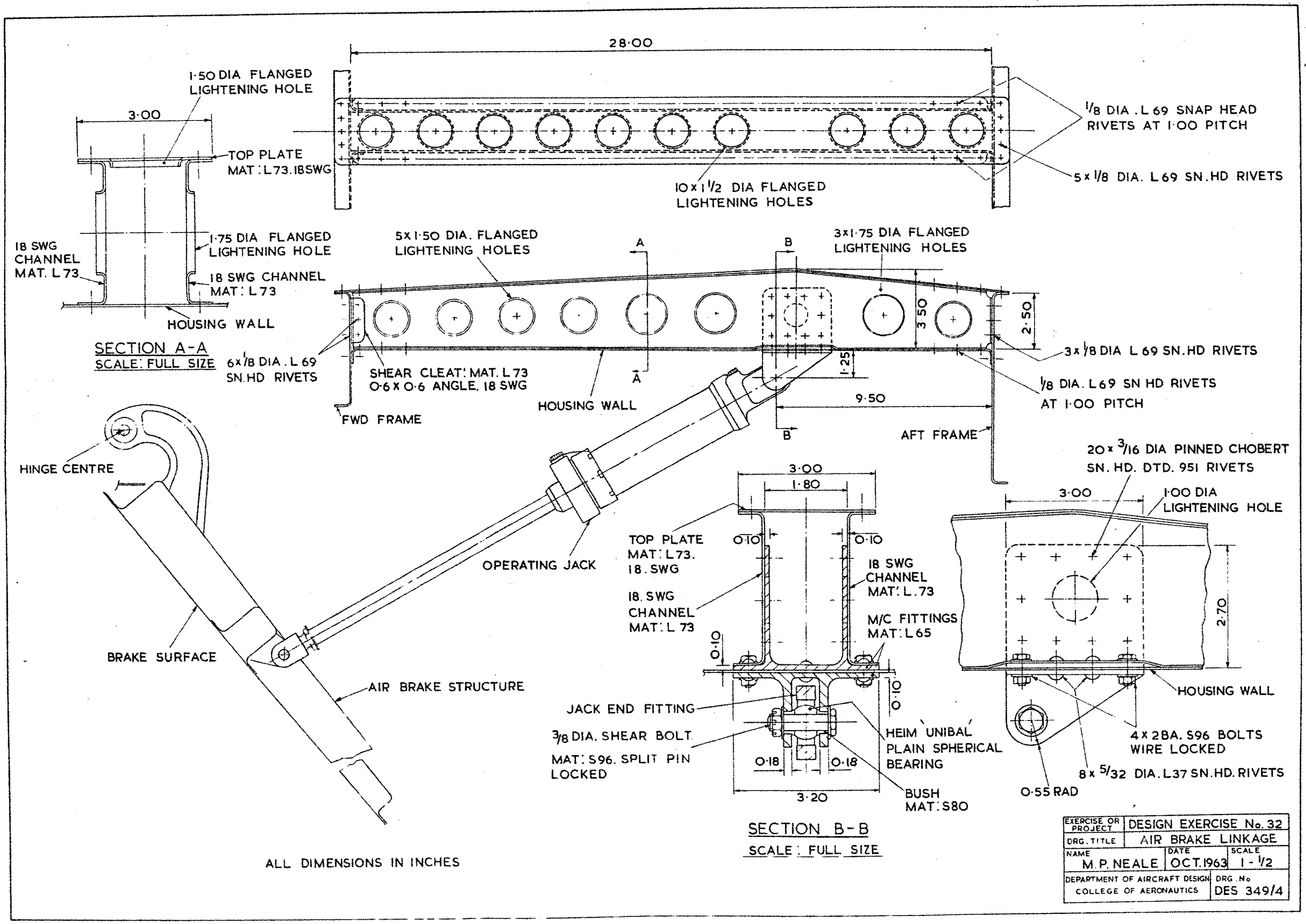


FIG. 6. COMPLETED DRAWING OF 1st TERM EXAMPLE.

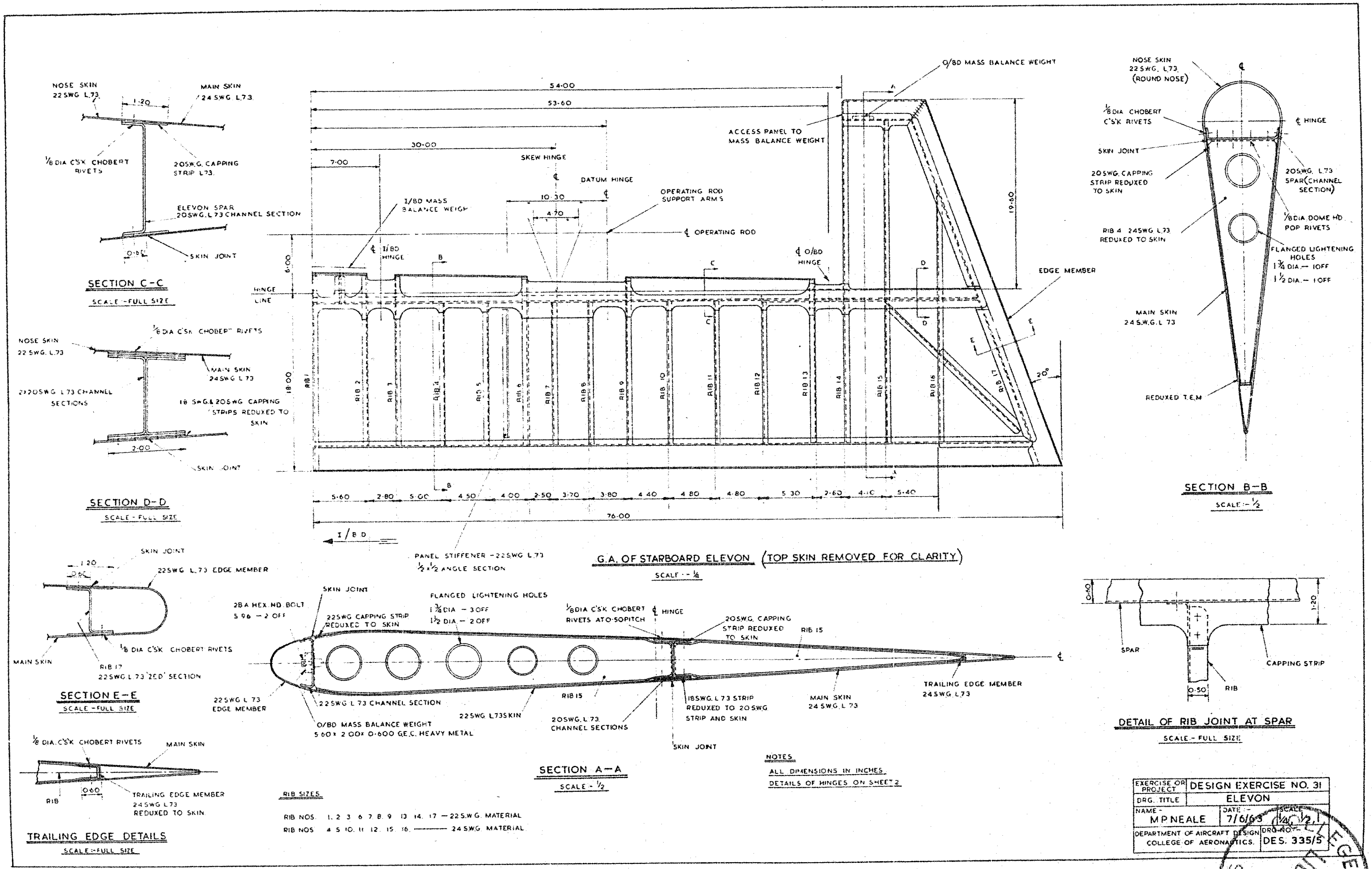


FIG. 7. COMPLETED DRAWING OF 3rd TERM EXAMPLE -SHT. I.

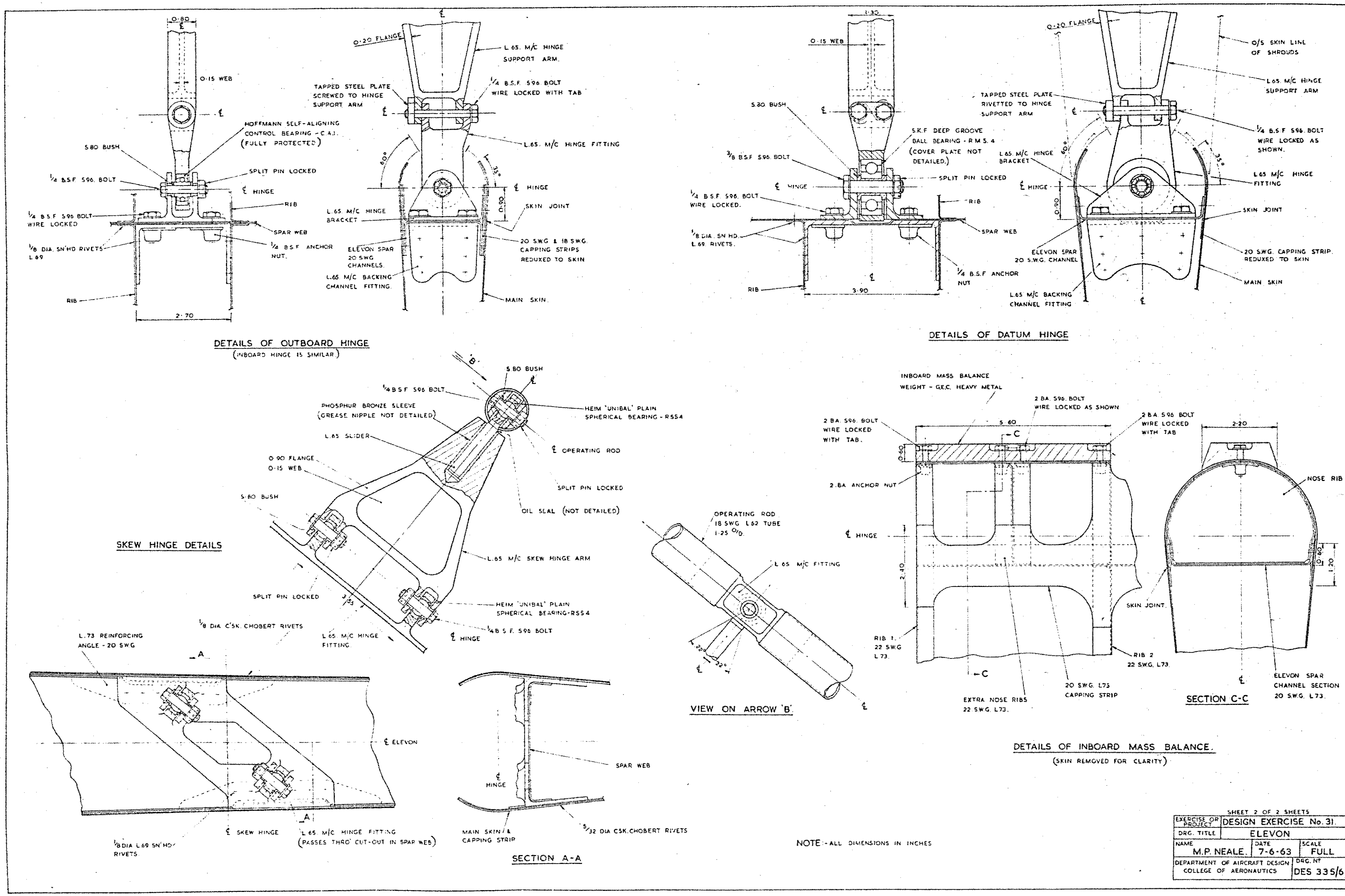


FIG. 8. COMPLETED DRAWING OF 3rd TERM EXAMPLE – SHT. 2.

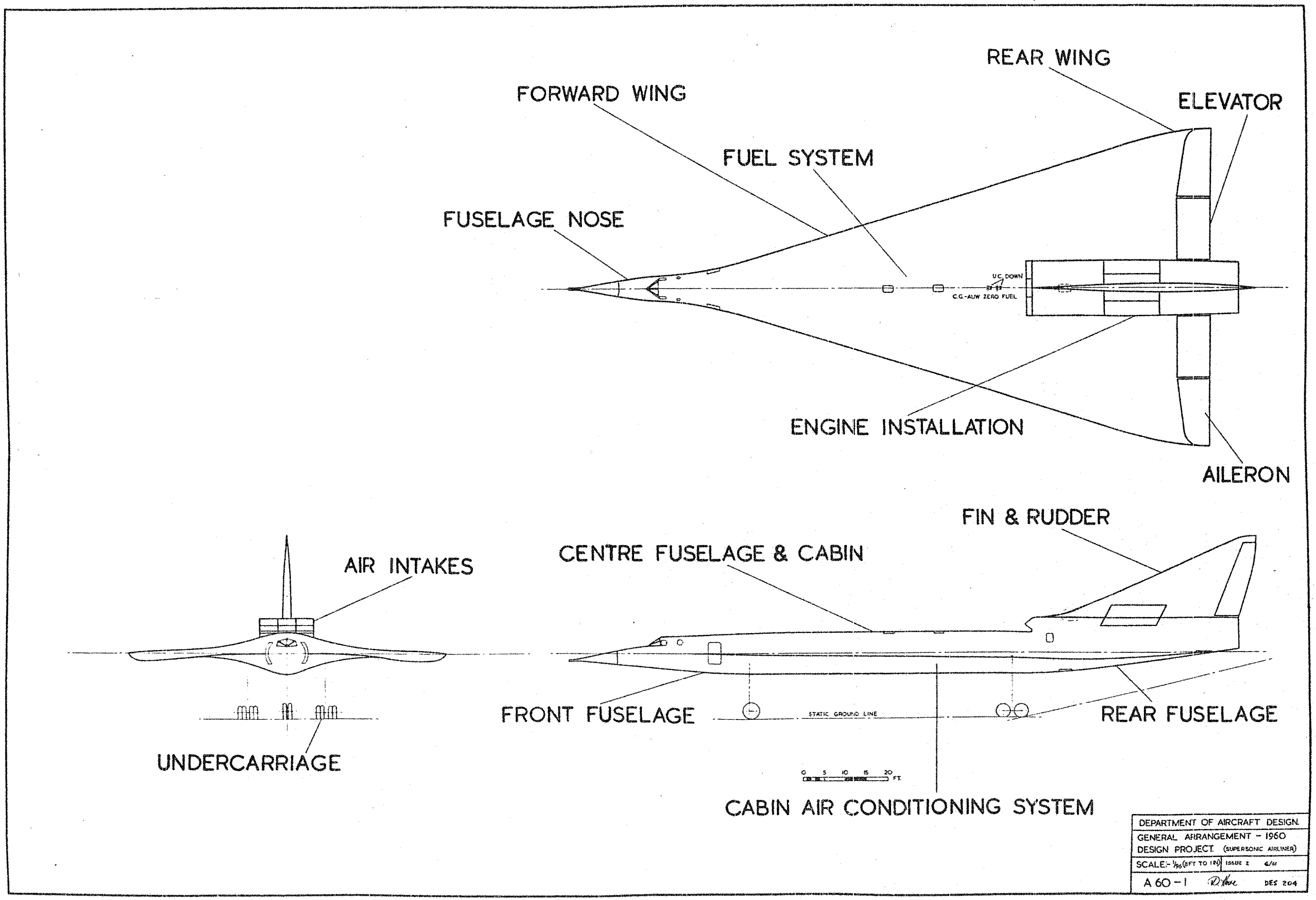


FIG. 9. COMPONENT ALLOCATION ON A 2nd YEAR PROJECT